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The Associated Electric Cooperative Energy Control System

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THE ASSOCIATED ELECTRIC COOPERATIVE ENERGY CONTROL SYSTEM

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ABSTRACT

Associated Electric Coop. installed a digital computer energy control system in 1971 to improve the economics and security of its power system operation. Since its initial implementation, the new energy control system has been undergoing a continuing evolutionary process. The addition of new data acquisition systems, improved man-machine interfaces, and the development of new, more sophisticated application programs has helped bring the system closer to its goal of reliable, secure, and economic power system operation.

This paper describes Associated's energy control system as it was originally installed, as it is currently operating today, and as it is currently envisioned to operate in the future. Emphasis is placed on the evolutionary nature of the automation of power system operations in light of the growth of the power system, its increased complexity, and the ever advancing technology of power system computer applications.

INTRODUCTION

Associated Electric Cooperative, Inc. is an electric cooperative corporation organized under the laws of the state of Missouri, with headquarters in Springfield, Missouri. It comprises the following electric generation and transmission (G&T) cooperative members which operate in the states of Missouri, Iowa, Kansas, Nebraska, and Oklahoma.

Central Electric Power Cooperative
Jefferson City, Missouri

M&A Electric Power Cooperative
Poplar Bluff, Missouri

Northeast Missouri Electric Power Cooperative
Palmyra, Missouri

N.W. Electric Power Cooperative, Inc.
Cameron, Missouri

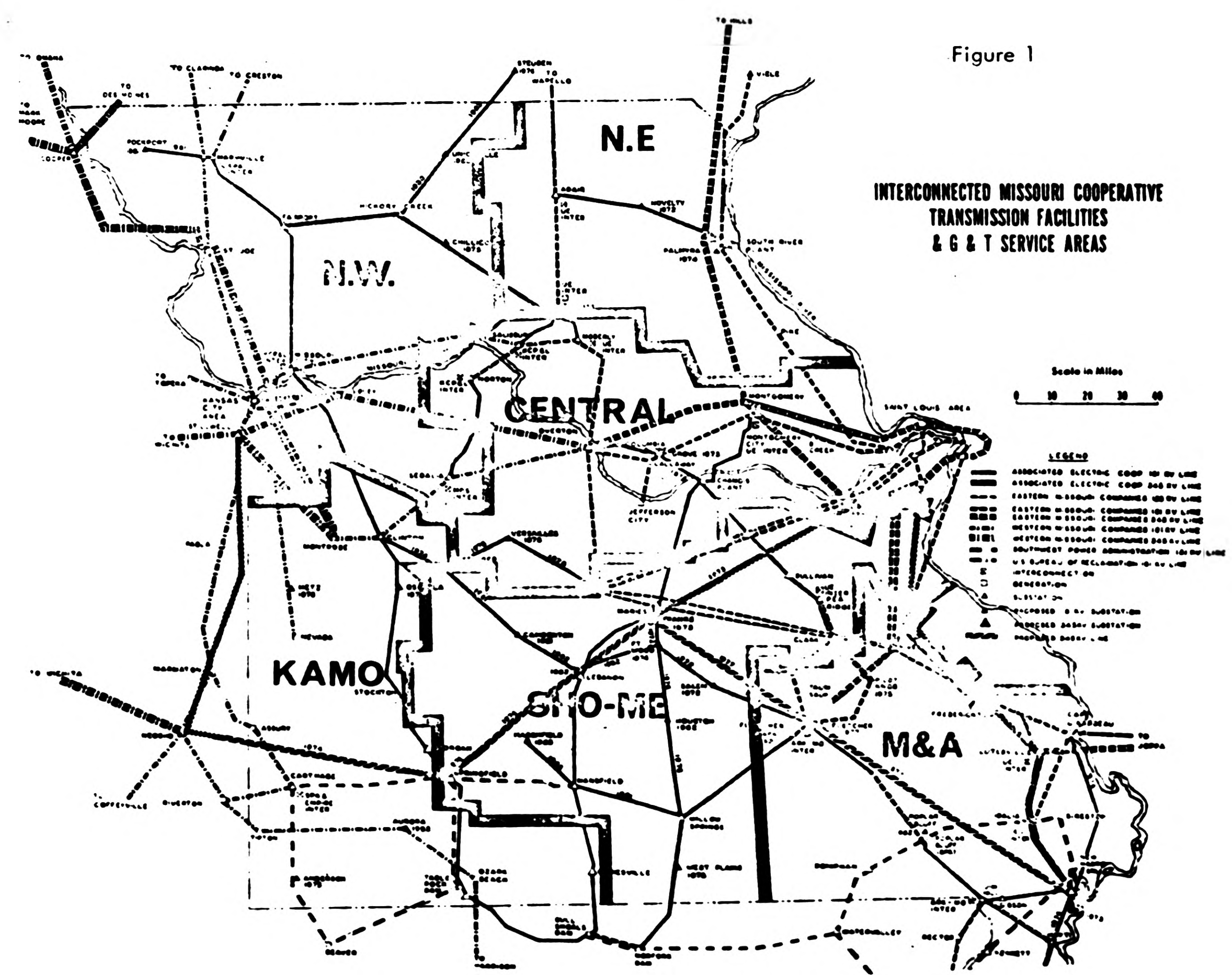


Figure 1

Sho-Me Power Corporation
Mansfield, Missouri

KAMO Electric Cooperative, Inc.
Vinita, Oklahoma

Associated was formed for the purpose of supplying its members with electrical power and energy at the lowest practical cost by utilization of the power sources and transmission lines available to it. Associated is, with minor exceptions, the sole supplier of the power requirements of its members. The member G&T's are, in general, the sole power suppliers of 43 member distribution cooperatives in Missouri and Iowa. These members distribute electricity to approximately 320,000 customers in the state of Missouri.

The Associated system peak load for 1973 was 910,000 kW, and electric energy sales for 1973 were over 4,150,000,000 kWh. The total present generating capacity is 1,225,000 kW with 600,000 kW of additional generation under construction for completion in 1977.

The bulk transmission facilities (Figure 1) of the system are composed of some 1422 miles of 345, 161, and 138 kV lines, which are used primarily for the transmission of power to the Distribution Cooperatives' 69 kV distribution systems. This power is transmitted through some 35 161-69 kV, 161-138 kV, and 345-161 kV substations having an installed transformer capacity of approximately 2967 MVA.

Associated is interconnected with some 14 operating utilities in the states of Missouri, Iowa, Kansas, Oklahoma, and Arkansas at 44 tie points.

The operation of the power system is coordinated from Associated's system Control Center which is located at its headquarters in Springfield, Missouri. Communications between the control center and the power plants, points of interconnection with other utilities, metering points necessary for system control is via a private microwave system.

Power System Operations

The primary goal in the operation of an electric power system is to supply the power required to meet customer demands in an economical manner consistent with system security. In order to achieve this goal, power system operations personnel are required to perform continuous and comprehensive analyses to evaluate the current system performance and to ascertain the effectiveness of alternative plans of operation. These analyses can be classified as operations planning, operations monitoring and control, and operations accounting and review.

The problems of operations planning involve calculations required to reach decisions concerning the next hour, day, week, or month of system operation. These analyses include the following: 1. Load Forecasting 2. Maintenance Scheduling 3. Spinning Reserve Determination 4. Unit Commitment Scheduling 5. Interconnection Transactions Evaluations.

Operations monitoring and control are involved with those problems requiring instant-by-instant determination on a real-time basis. These tasks include: 1. Monitoring and Alarming 2. Economic Allocation of Generation 3. Load and Frequency Control 4. Voltage and/or var Scheduling 5. Remote Supervision of Transmission Facilities.

Operations accounting and review analyses involve after-the-fact evaluations such as: 1. Interconnection billing 2. Energy Accounting 3. System and Unit Production Statistics 4. Post Disturbance Review Analysis

In each of these areas of power system operations the key considerations are economy and security of system operation. Because of the size and complexity of today's large, interconnected power systems, analog and/or digital computer systems are required to perform many of these operating functions in order to insure reliable and economic power system operations.

The paper that follows describes the automation of Associated's power system operations. The evolution of Associated's energy control system is traced from the installation of an on-line digital computer control system in 1971 to its current status. Future plans for energy control system improvements are also discussed to ascent the continuing process of automation.

AEC ENERGY CONTROL SYSTEM

In 1971, Associated installed a new digital dispatch computer system to improve the monitoring and control of its power system operations. An important constraint on the design of the new digital control system was that it be compatible with the existing control equipment. This constraint was improtant both from economic and reliability standpoints, since it both minimized the amount of new hardware required and allowed the existing control equipment to perform the backup function for the new system.

Existing Control Equipment (prior to 1971)

The existing equipment consisted of an analog telemetering system, chart recorders, an analog load frequency controller, a kWh digital telemetering system, and a kWh digital log unit. The operation and function of this existing equipment was as follows:

1) Analog Telemetering System - Power flows (MW) at all tie points (interconnections) and generator power outputs (MW) for all major generating stations are continuously transmitted into the control center over the microwave system where they are converted to analog values (mV).

2) Chart Recorders - All the telemetered MW values as well as system frequency, net interchange, scheduled interchange, area control error, system load, and total generation values are continuously trended on recorders.

3) Analog Load Frequency Controller - The telemetered tie flows and generator outputs are fed into the Analog Load Frequency Controller where the system control error and unit control errors (required adjustments to unit generations) are continuously calculated. Raise or lower commands are transmitted to the generating stations to effect the required changes in generation to minimize the system control error.

4) kWh Digital Telemetering System - At each tie point the interchange of energy (MWh) is metered, and at the end of every hour is transmitted into a digital receiver at the control center.

5) kWh Digital Log Unit - Once an hour, after all the metered energy values have been received, the kWh digital log is printed for use in energy accounting.

New Digital Computer System

The new digital computer system was a General Electric GE-PAC 4020 process control computer. It consisted of a central processing unit (CPU) with 24 k words (24 bits) of core memory, 131 k words of magnetic drum memory, 1024 k words of magnetic moveable-head disk memory, as well as process I/O subsystems, standard data processing peripherals, and CRT display subsystems. The process I/O equipment included both high speed analog and digital I/O subsystems and related equipment for interfacing with the existing control equipment. The standard data processing peripherals included a 300 CPM card reader, a 100 CPM card punch, a 300 LPM line printer, and I/O typer, and two output-only typers.

The new system also included two CRT display subsystems. Each CRT subsystem has two 14-inch black and white display terminals (a total of four for the system). Each terminal has the capability of displaying any of the 64 alphanumeric (A/N) characters in any position of a 22 row--46 column matrix. An electronic A/N keyboard was provided for data entry on only one of these terminals. These CRT subsystems were interfaced to the computer system via two half-duplex, bit-serial communication links -- the subsystem with the keyboard using a 4800 baud synchronous communications unit and the other a 1200 baud asynchronous communications unit.

To coordinate and control the operation of the GE-PAC 4020 computer system hardware described above, a Real-Time Multiprogramming Operating System (RTMOS) was also included. RTMOS is a grouping of programs and subroutines which supervises the inter-action of process events, time, actions by peripherals, and the CPU. RTMOS takes care of details such as responses to interrupts, scheduling of functional programs, allocation of core resources, input/output code conversions, input/output mechanics, monitoring of peripheral device status, substitution of peripheral devices, transferring of programs and data, as well as many other functions.

In addition to the standard GE-PAC RTMOS software, a background processing package, FREETIME IV, was also provided. FREETIME IV is a non-real-time batch processing function which provides for the compilation and assembly of FORTRAN IV and Process Assembly Language (PAL) programs and for program testing and debugging, and program and data table library maintenance. FREETIME IV operates while the computer system is on-line by making use of the frequent, relatively short intervals, when the computer system is not involved in active process monitoring and control. The card reader, card punch, and line printer peripherals are used primarily by this function.

Power System Operations Functions Performed

The following is a brief discussion of the salient features performed by the new digital dispatch computer system. Because of space limitations, the descriptions are brief and supporting functions are not described.

Data Acquisition -- One of the most basic and most important functions performed by the digital computer system is the acquisition of system information. This system information is of two types -- data and status. Data consists of the MW values, which are continuously telemetered into the control center from tie points and generating stations, and the frequency error, miscellaneous generation, and miscellaneous interchange values, which are derived from the analog control system. The status information indicates the condition of each of the telemetered data values. The status of the analog telemetering for each data value can be either in service, out of service, or in failure. Data values are input into the system through the analog to digital (A/D) converter while the status is a digital input. System information is acquired and updated in the system data base on $2\frac{1}{2}$ second intervals.

System Monitoring -- The system monitoring function is also performed every $2\frac{1}{2}$ seconds. It consists of the checking of the current system status for any abnormal conditions which should be alarmed. These checks include the failure of analog telemetering for extended periods of time, the input of unreasonable data values, tie line limit violations (excessive power flows), generator operating limit violations, and various system operating limit violations, such as excessive area control error.

Man-Machine Interface -- The operator's interface to the new digital dispatch computer system includes CRT display equipment, log typers, and chart recorders. The operator's console, through which the operation of the system is controlled consists of two CRT's and an A/N keyboard which has 45 function keys in addition to the standard A/N keys and entry marker (cursor) positioning keys. Through the keyboard, the operator can demand displays of various system status and parameters on either CRT as well as perform entries of various operating parameters. One CRT is used for entries and displays, the other is used for system alarms and displays. Displays of system status are periodically updated to insure the integrity of the data displayed.

In addition to the two CRT terminals used for the operator's console, there are two CRT's which are used for management information displays. Any one of four preselected displays can be called up for display through a four-button panel located with each CRT.

Two IBM Selectric 15 CPS typers are also part of the operator's interface. One typer is used for printing alarms and recording operator entries, the other typer is used for the printing of CRT displays and logs, either on demand and/or at periodic intervals.

The chart recorders are used to trend important calculated system variables. They include area control error, net interchange, scheduled net interchange, net generation, and system load. These recorders can be driven by either the analog or the digital control systems.

Automatic Generation Control -- Automatic generation control (AGS) consists of the system area control error (ACE) calculation, economic dispatch calculation (EDC), and load frequency control (LFC) functions. Since AGC is the primary operation performed by the new digital system, it will be explained in more detail.

Every $2\frac{1}{2}$ seconds, after the data acquisition function has been completed, the ACE calculation is performed. This involves calculating the actual net interchange, the deviation from the mutually prearranged (or scheduled) net interchange, and the area control error itself. ACE is the sum of the net interchange deviation and the frequency error derived from the analog system. The ACE function also calculates the net system generation, system load, and other miscellaneous values.

The EDC function periodically determines the most economical operating points for generating units required to meet the current system load. The EDC function operates in two modes -- "system dispatch" mode and "control dispatch" mode. System dispatch calculations are performed every ten minutes, or whenever system load or generation changes significantly, and upon operator demand. The system EDC is performed in the conventional manner, using individual incremental heat rate curves for each generator and penalty factors derived from a system transmission loss computation using the standard "B" matrix approach. Both manually and automatically controlled units are dispatched.

Control dispatch calculations are performed every five seconds using fixed penalty factors representing the current system state as calculated by the last system dispatch. Only automatically controlled units are dispatched since manual units are not expected to change generation over the short intervals.

The LFC function is performed every 2½ seconds to control unit generations to meet system load and reduce the area control error. The LFC function operates in two modes -- normal and assist. The normal mode of LFC operation is when the area control error is within the normal deadbaud range (+25 MW, - 25 MW) -- when economic operation is desired. The area control error calculated by the ACE function is first distributed between all units on automatic control using control participation factors. These values are then added to the units' control dispatch generation basepoints to determine the new desired unit generations. The desired unit generations are checked against the economic operating limits and if violated, are set equal to the limit exceeded. The desired unit generations are next compared with the actual unit generations to determine unit control errors. The LFC function then determines the raise or lower (R/L) control outputs that are required to reduce the unit control errors for each unit based on each units' response rates. The R/L control outputs are then transmitted to the generating units to perform the required control action.

The LFC function switches from normal to assist mode when the area control error becomes excessive and remains in the assist mode until the area control error is recuded to within an acceptable tollerance (+5 MW, -5 MW). During the assist mode of operation economics are ignored, and all units are moved to reduce area control error within the constraints of the LFC operating limits and response rates.

Interchange Scheduling -- The interchange scheduling function enters and maintains records of mutually prearranged energy transactions with other interconnected utilities and periodically calculates the net scheduled interchange for the monitoring and control functions. The function allows the entry of up to 40 separate interchange schedules for any hour and a total of up to 320 schedules for a period beginning one day in the past and running up to a year in the future. Each schedule entry consists of the following information: 1) Interchange Company 2) Type of Interchange (firm, economy, etc.) 3) Starting and Ending Time and Date of Interchange 4) Amount (MW) and direction (purchase or sale) of Interchange.

Interchange studies — Two interchange study functions are included to assist the operators in costing of energy transactions -- hourly interchange negotiations (HIN) and hourly cost reconstruction (HCR). The HIN function is used to superimpose a one hour schedule on the system for a future hour to determine the cost of the proposed transaction. The HCR function is used to compute the cost of interchange transactions for the past hour.

Energy Accounting -- The energy accounting function collects MWh data for all ties and generators in the system, updates the system energy data base, and prints hourly energy summary logs. Energy data is collected in two ways -- from the kWh digital telemetering receivers through a special digital I/O interface and by integrating the analog telemetered MW values on periodic intervals. The results are compared and large discrepancies are alarmed. The hourly energy log is printed on the log typer at the end of each hour. It contains both the metered and integrated values for ties, the integrated values for generators, and a system energy summary. This information can also be displayed and edited through the CRT console.

Post Disturbance Review -- The post disturbance review (PDR) function provides a record of system data which may be studied following a system disturbance. Data is collected continuously and maintained in revolving files such that at any point in time, when a disturbance might occur, there will be a record showing the data readings prior to the disturbance. All MW values for generators and ties are stored at ten second intervals and maintained for five minutes. When a PDR is demanded, the last five minutes of data is dumped on the line printer (optionally on cards). After five minutes of additional data is collected, a second dump occurs. This provides ten minutes of data for review - five before and five after a disturbance.

Contingency Evalutaion -- The purpose of the contingency evaluation (CEP) function is to compute the effects of a set of contingencies on a unique set of transmission lines in the system. A quantity, called a contingency distribution factor, is defined as the change in power flowing in a given line for a one per-unit change of power in some designated line or generator. These quantities are used to predict the power that would flow in each line if a designated line or generator were lost. The resulting line power flows are checked against line loading limits, and if a violation occurs, an alarm is output. The CEP function is performed periodically whenever an EDC (system dispatch) occurs.

Dispatcher's Load Flow -- A 127-bus dispatcher's load flow program is also included. It runs as a FREETIME IV program with card reader and I/O typer input and line printer output. Up to ten study cases can be stored in the disk files.

ENERGY CONTROL SYSTEM IMPROVEMENTS

Since its initial installation in 1971, the new digital dispatch computer system has been undergoing constant change. The addition of new data acquisition systems, improved man-machine interfaces, and the development of new, more sophisticated application programs have helped bring the system closer to its goal of more reliable, secure, and economic power system operation. The following section contains brief descriptions of some of these changes. The current system hardware configuration is shown in Figure 2.

Supervisory Control and Data Acquisition

In 1972, a GE-TAC supervisory control and data acquisition system (SCADA) was added to the existing ECS. It consisted of a GE-TAC Remote Station which was installed at a new 161/345 kV substation located at the site of the new 600 MW City of New Madrid generating plant and a GE-TAC Supervisory Communications Coupler on the GE-PAC 4020 computer system as well as new supervisory data acquisition and control software functions. Through the SCADA system, the system operators are now able to remotely monitor and control the operation of one of the most critical substations in the system (600 kV transmission line, 161/345 transformer rated at 350 MVA, and 345 kV transmission line).

Improved Man-Machine Interfaces

Three major improvements have been made with respect to the dispatcher's CRT console. First, a second duplicate CRT console has been installed to improve the reliability of and the accessibility to the primary operator's interface with the computer system.

Second, CRT display and entry formats and procedures have been modified or changed extensively to improve the efficiency and effectiveness of the dispatcher's consoles. Additional displays have also been added for the SCADA system.

Third, a small push-button panel has been added to the dispatcher's console to supplement for several lengthy CRT console procedures, which are performed at frequent intervals, and to display the raise and lower control outputs which are transmitted to the generating units. Through a simple one-button procedure, the operator can put a generating unit on control or take it off.

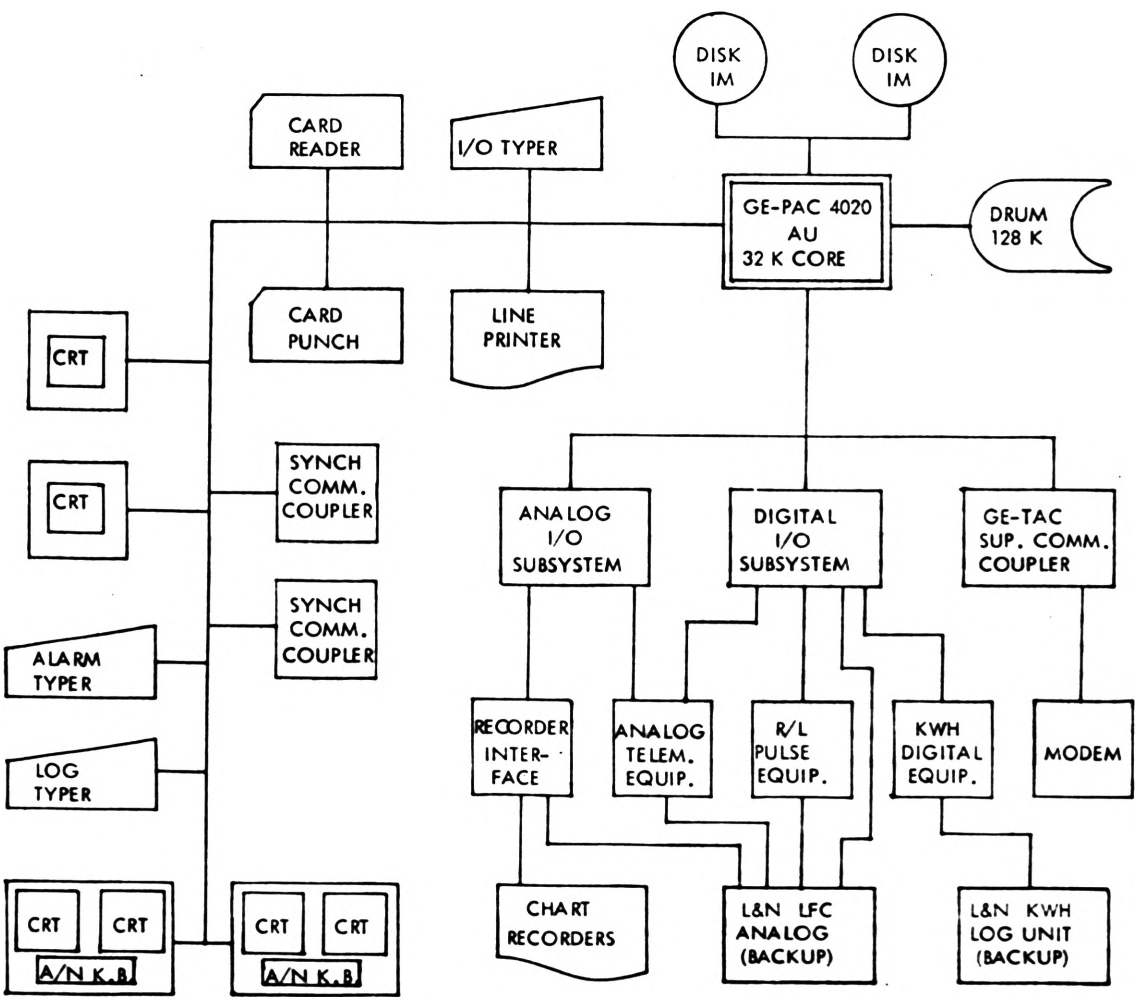
With a simple three-button sequence, the operator can select a display of the scheduled interchanges with any company and schedule type for either yesterday, today, or tomorrow. This display can then be edited to enter or modify any transaction. Through a similar one- or two-button prodecure, a summary of the net system schedules of the net schedules with any company or the net system schedules of any type can also be selected for yesterday, today, or tomorrow.

Additional Memory

The original 24 k core memory has been expanded to 32 k and an additional 1024 k word disk unit has been added. This additional memory provides required capacity for system expan-

Figure 2

THE GE-PAC 4020 SYSTEM BLOCK DIAGRAM



sions and for the development and implementation of new functional software.

G&T Data Links

Two of the member generation and transmission (G&T) coops. (Sho-Me and Central) are installing mini-computer supervisory systems to monitor and control the critical components of their transmission facilities. These new supervisory systems are being tied into the ECS through two 2400 baud, bit-serial synchronous communications links. Through these links, the ECS will acquire data on the operation of these systems for monitoring and display. In addition, the G&T systems will be able to make use of the GE-PAC 4020 resources to perform various analyses and studies from a remote terminal on their computer system.

Dispatcher's Load Flow (500-bus)

The original 127-bus load flow program has been modified to handle 500-buses and 1250 lines. The 127-bus load flow was never used, since its 200 line limitation was not adequate to handle the 126-bus reduced AEC system.

Dispatcher's Energy Log

A new comprehensive dispatcher's energy log is currently being developed. The new log will provide both daily and monthly summaries of all energy transactions, metered energy interchanges, and all system generation, load, and interchange statistics. The data base for the log printer will be accessible from the CRT console for review and editing. Logs will be printed on the line printer on demand.

FUTURE PLANS

In 1971, Associated installed a new digital computer energy control system to improve the reliability and economy of its power system operations because of the increased size and complexity of the power system. Since that time, many additions and improvements have been made to the new control system in response to the definition of new areas for automation and the redefinition of existing functions. Because of the new ECS, the reliability and economics of Associated's power system operations have been improved.

It would be terribly short-sighted at this point, however, to think that the job of power system operations automation is complete. The size and complexity of the power system increases every year. (The AEC system load has been increasing at a rate of more than ten percent per year for several years now, and the trend is expected to continue.) New large generating facilities, new EHV transmission facilities, additional ties with other utilities, and increased loadings on existing generating and transmission facilities will create new requirements for increased system security. Environmental concerns and the recent energy crisis will place new emphasis on system economy and the improved efficiency of energy generation and transmission as well.

Significant advances in the design of control systems and related data acquisition, communications, and display equipment have been made in recent years. Increases in computing power, real-time power system data collection capability, and effectiveness of man-machine interfaces as well as major advances in the formulation and development of new control, monitoring, and security analyses now make it possible to develop and implement advanced energy control systems to further improve the reliability and economy of operations of today's ever increasingly complex power systems.

Some of these advanced energy control system functions which are envisioned to be performed by the Associated ECS in the future are:

1) On-line Short-term System and Bus Load Forecasting
2) On-line Unit Commitment Scheduling
3) On-line Spinning Reserve Determination
4) On-line Power System State Estimation
5) Optimal Power Flow and Direct Economic and Security Dispatch of both Real and Reactive Power
6) Security Analyses based on On-line Load Flow Calculations

A redundant digital backup system, a digital telemetering system, and colored, limited graphics CRT consoles are also envisioned for the future.

Advances in automation technology have been very rapid in recent years, and it is very difficult to predict exactly what the state of the art will be next year, let alone five years from now. For this reason, it is very difficult to predict exactly how the Associated ECS will change in the next few years to meet the new challenges it will face for improved system security and economics. It is safe to say, however, that the evolution of the ECS will continue, and that the quality of power system operations will improve.

Biographical Sketch of Douglas W. Arlig

Douglas W. Arlig was born in Winchendon, Massachusetts, on April 23, 1947. He received a B.S.E.E. degree from Tufts University, Medford, Massachusetts, in June of 1969, and is scheduled to receive a M.S.E.E. degree from Arizona State University, Tempe, Arizona, in May of 1974.

He was employed by the General Electric Company in the Power Systems Automation section of their Process Computer Department in Phoenix, Arizona, as a programmer from June, 1969, to May 1972. He is presently employed by Associated Electric Cooperative, Inc. in Springfield, Missouri, as System Programmer with responsibilities for the maintenance, development, and implementation of automation systems for power system operations.

Mr. Arlig is a member of M.S.P.E. and I.E.E.E. He is also a member of the Power Engineering and Computer Societies of the I.E.E.E.